

## California High-Speed Train Project



**Agreement No.: HSR 13-06  
Book 3, Part B, Subpart 2**

# **Reliability, Availability and Maintainability**

HSR 13-06 - EXECUTION VERSION



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# 1 General Requirements

The Contractor shall perform the activities and provide the deliverables specified in this Reliability, Availability, and Maintainability (RAM) document for Construction Package 01 (CP01).

## 1.1 Reference Codes and Standards

Table 1 identifies reference standards.

**Table 1: Reference Standards**

ID	Issued By	Title
49 CFR Part 237	FRA, DOT	Code of Federal Regulations Title 49 Part 237 – Bridge Safety Standards
-	AREMA	Manual of Railway Engineering (2012 Edition)
EN 50126-1:1999	CENELEC	Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 1: Basic requirements and generic process
EN 50126-2:2007	CENELEC	Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 2: Guide to the application of EN 50126-1 for safety
EN 50126-3:2008	CENELEC	Railway applications - The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) - Part 3: Guide to the application of EN 50126-1 for rolling stock RAM
EN 50128:2011	CENELEC	Railway applications — Communication, signaling and processing systems — Software for railway control and protection systems
IEC 60300-3-11:2009	IEC	Analysis techniques for system reliability – Procedures for failure mode and effects analysis
IEC 60812	IEC	Analysis techniques for system reliability – Procedures for failure mode and effects analysis
IEC 60863	IEC	Presentation of reliability, maintainability, and availability predictions
IEC 61025	IEC	Fault Tree Analysis
IEC 61078	IEC	Analysis techniques for dependability – Reliability block diagram method
IEC 61165	IEC	Application of Markov Techniques
MIL-STD-785B	U.S. D.oD.	Reliability Program for Systems and Equipment, Development and Production
MIL-STD-217F Note 2	U.S. D.oD.	Reliability Prediction of Electronic Equipment



ID	Issued By	Title
MIL-STD-470B	U.S. D.o.D.	Military Standard: Maintainability Program for Systems and Equipment
MIL-STD-810G	U.S. D.o.D.	Environmental Engineering Considerations and Laboratory Tests
MIL-STD-471A	U.S. D.o.D.	Maintainability Verification / Demonstration / Evaluation
--	RiAC	Reliability Toolkit: Commercial Practices Edition
NPRD-2011	RiAC	Nonelectronic Parts Reliability Data

## 1.2 Acronyms and Abbreviations

Table 2 lists acronyms and abbreviations used in this document.

**Table 2: Acronyms and Abbreviations**

Acronyms and Abbreviations	
CHSTS	California High-Speed Train System
CMA	Corrective Maintenance Analysis
CP01	Construction Package 01
CRMP	Contractor RAM Program Plan
DC	Design Criteria
EN	Euro Norm
FMEA	Failure Modes and Effects Criticality Analysis
FTA	Fault Tree Analysis
HPMR	Historical Product Maintainability Report
LLRU	Lowest Level Replaceable Unit
LRU	Line Replaceable Unit
MDTP	Maintainability Demonstration Test Plan
MRTT	Mean Repair Travel Time
MTBF	Mean Time Between Failures
MTBSF	Mean Time Between Service Failures
MTTR	Mean Time To Restore
MTTRS	Mean Time To Restore Service Failure
PM	Preventative Maintenance
PMA	Preventive Maintenance Analysis
PMT	Project Management Team
RAM	Reliability, Availability, and Maintainability
RAMPP	Reliability, Availability, and Maintainability Program Plan
RAMS	Reliability, Availability, Maintainability, and Safety
RCM	Reliability Centered Maintenance
SCADA	Supervisory control and data acquisition
SONO	Statement of No Objection
V&V	Verification and Validation



## 1.3 RAM Definitions

The following definitions apply to this document:

**Availability** is the ability of an element of the CHSTS to be in a state to perform a required function under specified conditions over a specified time interval assuming that the required external resources are provided (**interval availability**).

**Corrective Maintenance** is the non-scheduled maintenance carried out after failure recognition, whose purpose is to restore a component of the CHSTS so it can perform its required function.

**Down Time** is a time interval during which any part of a component of the CHSTS is in a down or degraded state, e.g., is not able to perform its required function.

**Maintenance** is the combination of all technical and administrative actions, including supervision actions, intended to retain a component of the CHSTS in, or restore it to, a state in which it is able to perform the required function.

**Maintenance Window** is a time period scheduled in advance when no revenue trains operate, allowing maintenance employees to work on track or systems.

**Mean Time to Restore (MTTR)** is the average of Down Time that includes time to troubleshoot and fault- isolate a failure, remove and replace or repair faulty items, and perform functional check-out to verify restoration to operational status.

**Preventive Maintenance** is the scheduled maintenance carried out at pre-determined intervals or according to prescribed criteria whose purpose is to minimize disruption of revenue service.

**The RAM Program** is a documented set of scheduled activities, resources and events serving to implement the organizational structure, responsibilities, procedures, activities, capabilities and resources that together ensure that the CHSTS will achieve its RAM requirements.

**A Service Failure** is a failure which affects a CHSTS element and fulfills any of the following:

- It causes or could cause one or more trains to be delayed
- It causes one train to run in a more restrictive operating mode than would have otherwise been the case in its absence.

**The System Lifecycle** consists of all activities which occur from first System planning phase, through the development, implementation, operation and maintenance until the final decommissioning and disposing of the System.

**Up Time** is a time interval during which a component of the CHSTS is in an up state, e.g., fully able to perform its required function.



## 1.4 Contractor RAM Scope

The Contractor RAM Scope covers all the elements of Project scope defined in the Scope of Work document, in Book 2, Part C, and relates to the RAM characteristics of the Project elements in the future revenue service. This does not include the Warranty service and Warranty service plan delineated in General provisions, Book 2. In general, RAM criteria for the Work include design life, and codes and standards to be applied such as seismic design standards and flood level considerations; and maintainability features to achieve the required service life of the Project elements per the Design Criteria, directive drawings, other contract documents, and quality control and assurance processes.

## 1.5 Contractor RAM Tasks and Deliverables

The Contractor shall:

- Design, build, and document the Project per the RAM requirements set in this Procurement package, including the RAM requirements set in the Scope of Work, Book 2, Part C and the Design Criteria Manual, Book 3, Part C.
- Develop and implement a Contractor RAM Program Plan (CRMP)
- Coordinate RAM and Safety work
- Use and document appropriate RAM design criteria and methods in design and construction
- Develop detailed RAM allocations for subsystems and elements
- Perform RAM analyses for the Work in all design phases
- Ensure that its suppliers and subcontractors perform all needed work to fulfill the RAM requirements
- Provide all necessary reports and documentation and track them in a compliant Verification and Validation (V&V) process, per V&V and Self-Certification requirements in Book 3.

The Contractor shall perform RAM tasks as delineated in this document and provide the submittals as per Table 3. For details see the respective sections.



**Table 3: Contractor RAM Deliverable and Schedule**

<b>Section</b>	<b>Deliverable</b>	<b>Timeframe</b>
2	Contractor RAM Program Plan (CRMP) - Draft	NTP+60 days
	- Final	NTP+90 days
3	RAM Allocation Report	Baseline Design Report
4	Historical Product Maintainability Report (HPMR)	Baseline Design Report
5	Maintenance Manuals	Final Design Report
6	Reliability-Centered Maintenance (RCM)	Final Design Report
7	Preventive Maintenance Analysis (PMA)	Final Design Report
8	Corrective Maintenance Analysis (CMA)	Final Design Report
9	Maintainability Demonstration Test Plan and Procedure (MDPP)	Final Design Report
9	Maintainability Demonstration Test Report (MDTR)	Before or with Substantial Completion approval request

Each RAM submittal is subject to Statement of No Objection (SONO) review. Refer to V&V and Self-Certification requirements in Book 3.

## 2 Contractor RAM Program Plan

The Contractor shall develop and implement a Contractor RAM Program Plan (CRMP). The Contractor shall submit the CRMP for review per section 1.5 of this document.

In general, the CRMP shall:

- Compliant with all applicable CFRs including but not limited to 49 CFR Part 237 – Bridge Safety Standards
- Be consistent with EN 50126-1,
- Define RAM Program scope, tasks, techniques, deliverables, and milestones
- Provide a RAM Program schedule, which identifies specific tasks, with start and completion dates, and explains how these tasks are coordinated and integrated with the Project schedules
- Provide the organization of personnel responsible for performing the RAM Program
- Identify RAM allocations
- State methodology of the tasks to comply with the RAM requirements
- Provide demonstration testing plans for verification of compliance with RAM requirements



- Describe monitoring and control of subcontractors and suppliers
- Define interfaces and coordination with other assurance activities such as safety and quality assurance
- Provide supporting field reliability, availability, and maintainability data and estimates.

The CRMP shall establish procedures for the Contractor to track all necessary reports and documentation in a compliant Verification and Validation process, and submit them for review per section 1.5 of this document. The Contractor may include additional tasks or task modifications with supporting rationale for each addition or modification.

The CRMP shall provide all the necessary information and inputs for the future bridge management programs for the related Project elements as per the 49 CFR Part 237 – Bridge Safety Standards which will be adopted by the Authority in the revenue operation phase.

The Contractor can determine the best way to structure RAM compliance documents, provided that the required elements are addressed. Where a subcontractor is responsible for similar elements, such as several similar bridges, a single CRMP may suffice. Several different elements may be included in a CRMP, especially when there is a relationship between the elements, such as retaining walls and drainage systems. For unique and complicated elements, such as a tunnel or non-standard bridge, the Contractor may choose to provide a CRMP covering just that structure.

### 3 RAM Allocation Report

The Contractor shall provide a RAM Allocation Report, demonstrating that the Work will achieve required reliability, availability, and maintainability, for review per section 1.5 of this document. The report shall describe the basis for the RAM allocations.

In general, subsystem RAM allocations shall:

- Conform with the RAM requirements set in this Procurement package
- Include:
  - MTBF, where applicable
  - MTTR
  - MTBSF, where applicable
  - MTTRS
  - Interval availability
- Assign responsibility to subcontractors.



The Contractor may base RAM allocations on:

- Historical information
- Experience with similar elements
- Techniques such as Feasibility of Objective or Advisory Group on Reliability of Electronic Equipment (AGREE) Allocation Method

The Contractor shall provide RAM allocations for elements down to the subsystem level or lower. The Contractor shall submit the RAM allocations for review per section 1.5 of this document. RAM allocations will be used to assess compliance of the RAM analyses for subsystems or elements.

## 4 Historical Product Maintainability Report

The Contractor shall provide Historical Product Maintainability Report (HPMR) for review per section 1.5 of this document. The HPMR shall present RAM information based on previous applications of the elements.

In general, the HPMR shall designate each Project element and its components; indicate the subcontractor if applicable; identify previous application of the element and its components; demonstrate that the element meets the RAM allocations; describe the specific application, identifying any differences between the CHSTS design and previous applications; indicate the source, date, and reference contact for the element; and provide user certifications from the cited element applications.

The Contractor shall present historical maintainability information for the CHSTS elements, including corrective maintenance summaries, MTTR, preventive maintenance task descriptions, and task time per interval information from previous application of the element. In addition, the report shall detail any maintainability, accessibility, or interchangeability improvements or degradations related to design changes for the CHSTS. The Contractor shall provide historical scheduled preventive maintenance information consistent with the example in Table 4.

**Table 4: Historical Preventive Maintenance Task List**

Historical Preventive Maintenance Task List				
System / Subsystem / Element (or LLRU)	Preventive Task Title	Task Time Per Location (Man-Hrs)	Task Interval (month)	Special Tools



The Contractor shall provide a summary of corrective maintenance tasks performed on a given element for each cited previous application. The Contractor shall provide historical scheduled preventive maintenance information consistent with the example shown in Table 5. In the summary, the Contractor shall provide information including a description of the failing item, the failure mode, corrective action taken, time taken for repair, and any special tools required to facilitate the repair.

**Table 5: Historical Corrective Maintenance Summary**

<b>Historical Corrective Maintenance Summary</b>					
<b>System / Subsystem / Element (or LRU)</b>	<b>Failed Item</b>	<b>Failure Description</b>	<b>Corrective Action</b>	<b>Time To Repair</b>	<b>Special Tools</b>

## 5 Maintenance Manuals

The Contractor shall prepare and submit Maintenance Manuals for the Project elements for review as per section 1.5.

The Maintenance Manuals must identify and address the maintenance of the Project elements during the long term revenue service.

## 6 Reliability Centered Maintenance

The Contractor shall utilize a Reliability-Centered Maintenance (RCM) approach to determine Preventive Maintenance intervals and activities, and shall provide a Reliability-Centered Maintenance Report (RCMR) for review per section 1.5 of this document.

In general, RCM is intended to:

- Minimize downtime
- Maximize reliability and availability
- Minimize Life Cycle Cost (LCC)

Maintenance requirements shall balance system availability, reliability, risk, and life cycle costs. The Contractor shall base Preventive Maintenance tasks on results from:



- Reliability and risk analyses
- Maintainability analyses
- FMECA and Fault Tree Analysis (optional, where applicable)

The Contractor shall establish life limits on safety-critical elements so that the probability of failure-before-life-limits is acceptably small under normal deterioration. The Contractor shall also establish condition monitoring to detect whether deterioration was abnormal.

The RCMR shall identify any failure of the Work which can cause Service Failure and impact CHSTS operation.

The Contractor shall integrate RCM tasks with other project tasks, but not limited to the following:

- Special Tools List
- Maintainability Analyses
- Reliability Analyses
- Safety Analyses
- User Education
- Elements Design/Selection
- Design Reviews
- FMECA (where applicable)

The RCMR shall establish three PM task categories:

1. **Scheduled Restoration Tasks:** Time-driven repair, regardless of condition. AKA "Overhaul" or "Heavy Repair" maintenance.
2. **Scheduled Discard Tasks:** Time-driven replacement, regardless of condition. AKA "Remove and Replace" maintenance.
3. **Scheduled On-Condition Tasks:** The decision to repair/replace is dependent on the test for a condition that indicates that a failure is about to occur or is occurring. AKA "Predictive" maintenance.

The RCMR shall classify failure mode consequences into four groups:

1. **Hidden Failure Consequences:** Hidden failure modes are not directly announced and have no direct impact; however, they expose the system to multiple failures which can have serious consequences. Hidden failure modes can work in concert with other failure



modes to create a hazardous or failed operating condition. An example would be a protective device which is not fail-safe.

2. **Safety and Environmental Consequences:** A failure mode has safety consequences if it violates safety requirements set in this Procurement package. A failure mode has environmental consequences if it could lead to a breach of any Customer, State, or Federal environmental standard.
3. **Functional Consequences:** A failure mode has functional consequences if the failure mode effects the elements ability to fulfill any of its designed functional or performance requirements, including reliability and availability.
4. **Non-Operational Consequences:** Failure modes which are not hidden and do not have any safety, environmental, or functional consequences are classified as non-operating failure modes. These failure modes involve only the direct cost of the repair.

The RCM Decision Tool determines which element or equipment failure modes are addressed by which RCM failure management techniques. Figure 1 shows a typical RCM Decision Tool flowchart.

**Figure 1: The RCM Decision Tool Flowchart**

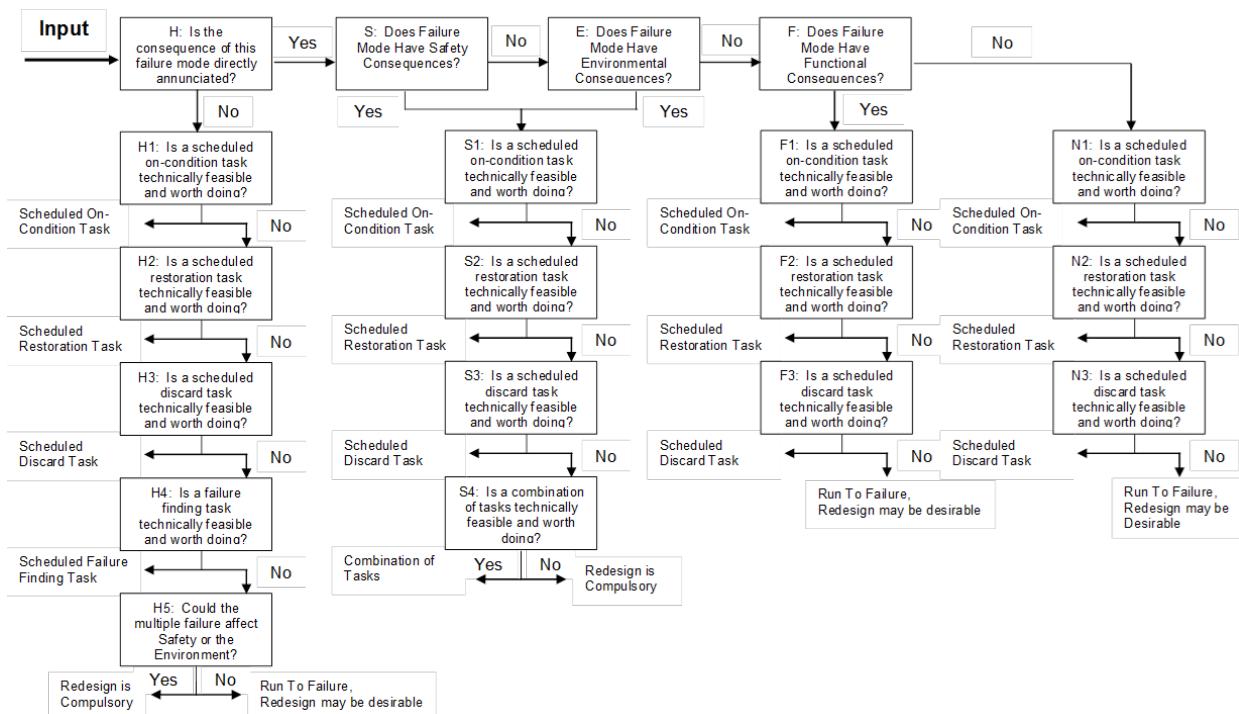


Table 6 shows a typical RCM Decision Tool output form. The analyst uses the results to develop proactive maintenance tasks or default actions, as appropriate.



**Table 6: RCM Decision Tool Output Form**

RAM Analysis No.	Failure Mode	RCM Failure Mode Category	RCM Failure Management Technique

The RCM Decision Tool shall include all tasks identified as necessary by RAM analyses, as well as tasks relevant to project-specific requirements. The following shall be defined for each maintenance task, as a minimum:

1. Task Title
2. Task Description
3. Task Interval
4. Maintenance Level
5. Personnel Skill Requirements
6. Number of Persons
7. Task Time per Location
8. Number Locations per subsystem
9. Total Task Man Hours
10. Man Hours per Year
11. Special Tool Requirements

## 7 Preventive Maintenance Analysis

The Contractor shall conduct a Preventive Maintenance Analysis (PMA) consistent with the RCMR, and provide a PMA Report for review per section 1.5 of this document. The Contractor shall submit periodic PMA Report updates until the task is concluded.

In general, PMA shall consist of a tabular summary of the Project elements preventive maintenance tasks. The goal of PMA is to ensure that all preventive maintenance tasks are



justified by RAM analyses, and that task intervals are appropriate. Table 7 shows a sample PMA table.

The PMA Report shall summarize all PM tasks identified in the RCM. The Contractor shall maintain traceability between the PMA Report and the Maintenance Manuals, to show that the Maintenance Manuals include all tasks required by the PMA.

**Table 7: Detailed RAM Analysis – Preventive Maintenance Summary**

<b>Detailed RAM Analysis – Preventive Maintenance Summary</b>					
<b>System / Subsystem / Element (or LLRU)</b>	<b>Preventive Task Title</b>	<b>Task Time Per Location (Man-Hours)</b>	<b>Task Interval (months)</b>	<b>Task Justification</b>	<b>Special Tools</b>

PMA Reports shall provide Preventive Maintenance Summary tables, identify issues, and describe actions to be taken. PMA Reports shall also provide a summary table, organizing preventive maintenance tasks per interval, and summarizing preventive maintenance task time per interval.

## 8 Corrective Maintenance Analysis

The Contractor shall perform a Corrective Maintenance Analysis (CMA) and provide a CMA Report for review per section 1.5 of this document. The Contractor shall submit periodic CMA Report updates until the task is concluded.

In general, the CMA shall consist of a tabular summary of the Project elements MTTRs. The goal of the CMA is to ensure that the elements supplied by the Contractor and all of its subcontractors meet the MTTR requirements. Table 8 shows a sample CMA table.

The CMA shall include each Project element and their components. Failure rates shall be per historical reliability data, Failure Modes, Effects, and Criticality Analysis (FMECA), or other verifiable source. The Contractor shall maintain traceability between the CMA Report and the Maintenance Manuals, to show that the Maintenance Manuals include all tasks required by the CMA.

The Maintenance Ratio is a function of the number of man-hours of corrective maintenance per hour of system operation. The Maintenance Ratio shall be used in the Maintainability Prediction worksheets to linearize the MTTR quantity so that the Maintenance Ratio can be linearly summed up to the system level from the Project element level.



CMA Reports shall provide the MTTR Summary tables, describe compliance with the RAM requirements and allocations, identify issues, and describe next steps.

**Table 8: Detailed RAM Analysis - MTTR Summary**

Detailed RAM Analysis - MTTR Summary							
No.	Element ID	element Name	Failure Rate	Qty	Corrective Maintenance Task	Time to Repair	Maintenance Ratio
<b>Overall Failure Rate</b>				<b>Overall MTTR</b>			

Maintenance Ratio = Failure Rate \* Qty \* TTR (man-hours)

MTTR = [Sum of all Maintenance Ratios] / Overall Failure Rate

The final CMA Report shall demonstrate compliance with the RAM requirements set in this Procurement package.

## 9 Maintainability Demonstration

The Contractor shall provide a Maintainability Demonstration Test Plan and Procedures (MDTP) for review per section 1.5, and shall perform a Maintainability Demonstration (MD), and provide a Maintainability Demonstration Test Report (MDTR) for review per section 1.5 of this document.

In general, the Maintainability Demonstration shall establish the accuracy of task time estimates for the preventive and corrective maintenance tasks described in the applicable Maintenance Manuals. The Contractor shall demonstrate selected servicing, preventive maintenance, troubleshooting, change out of components, corrective maintenance, and use of special tools where special emphasis, instruction, or proficiency is needed. CHSTS shall notify the Contractor which preventive and corrective maintenance tasks have been selected for the MD.

The Contractor shall develop and submit a Maintainability Demonstration Test Plan (MDTP) for review per section 1.5 of this document before the demonstration. The MDTP shall be consistent with MIL-STD-471.

The Contractor shall then perform the test according to the approved plan and procedures and provide a final test report.

